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Original Article

THERMAL PROPERTIES OF POLYMERIC COMPOSITES REINFORCED BY NANOCERAMIC MATERIALS

JAWAD. K. OLEIWI[1] & BASIM A. ABASS[2]

[1]*Department of Materials Engineering, University of Technology, Baghdad, Iraq*

[2]*Department of Mechanical Engineering, College of Engineering, University of Babylon, Babylon, Iraq*

ABSTRACT

The present work focuses on the effect of reinforcing polymer with TiO_2 and Al_2O_3 Nano-powders on its thermal properties since they have many important thermal applications. The effect of adding such Nano-powders with different particle percentages by weight (0.5%,1%, 1.5% and 2%) to the base material have been discussed. Different samples of the resulting Nano-composite materials have been prepared according to (ISO-220077) standard. Thermal properties of such samples have been evaluated by using hot disc technique and the results have been compared with that of pure epoxy. The results show that the thermal conductivity and thermal diffusivity increase with increasing weight fraction of reinforcing materials, and it becomes higher when the epoxy was reinforced by (Al_2O_3) rather than (TiO_2) Nano powder. Also the results indicated that maximum values of thermal conductivity and diffusivity of the Nano-composite specimen reinforced by 2% (Al_2O_3) were (0.55W/m.K) & (0.45 mm^2/Sec.) respectively. It has also shown that the heat capacity of the Nano-composite material decreases when the epoxy reinforced with Al_2O_3 and TiO_2Nano-powders with different weight fractions.

KEYWORDS: Epoxy, Composite, Thermal Properties & Nano Powder

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INTRODUCTION

Now a day the epoxy composite materials used in a wide range of temperatureswhich makes the study of thermal characteristicsfor such materials of great importance. Future materials may be high conductive and heat dissipated with low coefficient of thermal expansion. For this purpose many advanced materials have been produced to get the required characteristics. Many works have been carried out dealing the polymer composite materials that was widely usedin thermoelectric, aerospace, automotive, construction and many other fields [1]. These materials are extensively used in many industrial applications because of their good thermalconductivity, corrosion resistance, well tribological and mechanical properties like wear resistance and hardness [2] in addition to the process-ability and durability at elevated temperature [3]. Thermoplastic and thermoset are the most available matrices of the polymer composite materials. A good thermal conductivity is required for using these materials as insulating materials for power equipment, electronic packaging and encapsulations, computer chips, satellite devices and other areas. Molecular orientation or implementing highly conductive fillers in epoxy can be used to improve the thermal conductivity of such materials [4]. Some organic materials such as carbon nanotubes, graphite fibers and grapheneare used as organic fillers while alumina (Al_2O_3), and Boron Nitride (BN)areused as inorganic fillers [5, 6]. Aluminum Oxide, Zinc Oxide (ZnO), Zirconium Oxide (ZrO_2) are the most popular metal oxide fillers. Implementing these fillers to the polymer matrix enhances its tensile and flexural strength, hardness

and stiffness [7]. Epoxy resin is commonly used as a matrix for the composite materials. It isknownas polymericmaterial which characterized by highresistance to the adverse conditions, and good adherencewith the embedded fillers. Epoxy resin has many electronic applications when toughness and resistance to high temperatures are required [8]. Thermal properties of ABS blended with ZnO Nano-powder of different particle concentrations were studied by AW et al. [9]. It was observed that the thermal conductivity increased from 0.2204 W/m.K to 0.3508 W/m.K when the filler weight fraction increases to 14 %. The effect of Boron nitride Nano tubes on thermal properties of epoxy was investigated by Zhi et al. [10]. An improvement of 69% in thermal conductivity has been obtainedfor an epoxy that contains 5% boron nitride nanotubes. The effect ofmulti wall carbon Nano tubes (MWCNTs) and Boron Nitride (BN) on the thermal properties of epoxyNano composite material has been studied by Chiguma et.al. [11]. It was found that thermal diffusivity of Nano-composites filled with Boron Nitrideis higher than that obtained for graphite and MWCNTs filled Nano-composites. Thermal conductivity of polypropylene (PP) reinforced by titanium dioxide (TiO_2) and Boron nitride (BN) has been investigated by Standauet. al. [12]. It was found that the thermal conductivity increased by adding these fillers with different particle size distributions and concentrations. The main goal of the present work is to investigate the effect of adding(Al_2O_3) and (TiO_2) Nanopowders with different weight fractions to the epoxy on its thermal properties in order to introduce a composite material that might find thermal applications.

THEORETICAL PART

The study of thermal properties for the composite material is very important. It indicates the dependence of the material expansionon a particular change of temperature and how much the material temperature rises due to the input heat in addition to material heat conductance[13]. Ahot disk thermal analysis was used to estimate the Nano composite thermal properties. Transient Plane Source (TPS) technique was used to evaluate thermal properties of the Nano-composite material. The hot disk includes heat source and temperature probe as a flat sensor. The sensor was normally placed between the surfaces of the two pieces of the specimen to be measured during the test [14, 15]. The relationship between the thermal properties can be expressed as [16]:

$$D_{th} = \frac{K}{C_p \rho}$$

where:

$\boldsymbol{D_{th}}$: Thermal diffusivity (mm^2/s).

$\boldsymbol{C_p}$**:** Specific heat at constant pressure (J/ $m^3.^oK$).

$\boldsymbol{K}$: Thermal conductivity (W/m.^{o}K).

$\boldsymbol{\rho}$: Mass density (Bulk density) (kg/m^3).

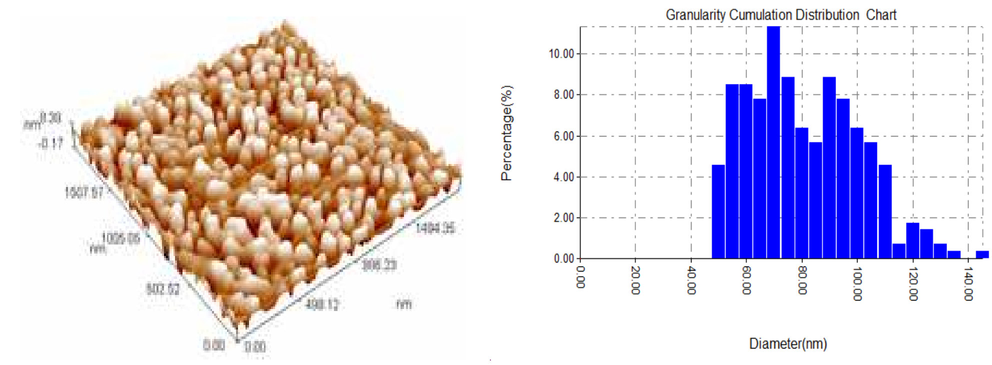
Experimental Part

Hot disk thermal analysis was performed according to the procedure implemented in apparatus manual of standard specifications [17]. The specimen was placed inside the devicewith the hot disk sensor is placed between two pieces of the same sample material prepared at the same standard dimensions according to the standard specification of the instrument. The sample dimensions should be larger than the sensor diameter to insure stable readings of both thermal conductivity and thermal diffusivity. The values of thermal conductivity, thermal diffusivity and specific heat are read from the

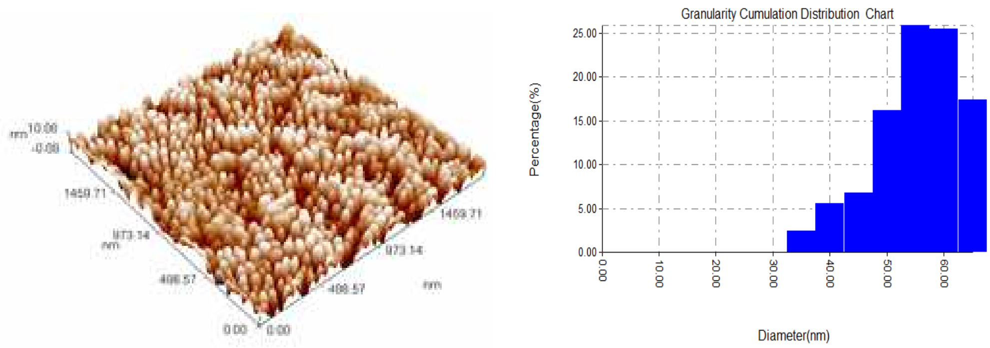
computerized gauge [18]. Test specimens made ofepoxy as a matrix reinforced by (Al_2O_3) and (TiO_2) Nano powders with different weight fractions (0.5 %, 1 %, 1.5 %, and 2% wt.). The epoxy supplied from Egyptian Swiss Chemical Industries Co. from Egypt. While the (Al_2O_3) and (Tio_2) Nanopowder supplied by a commercial source. The powders heated to 100^{o}C for six hours before use and then mixed with epoxy at room temperature. Atomic force microscope (AFM) was used to measure the average particle size of the TiO_2 and Al_2O_3 Nano powders. Thermal and physical properties of the epoxy and the Nano powders used in the present workare presented in Table (1) [19].

Table 1: MaterialsThermal and Physical Properties [19]

Materials	Density (g/cm^3)	Thermal Conductivity(W/m.K)	Thermal Diffusivity(mm^2/Sec.)	Specific Heat(J/kg.K)
Epoxy	1.2	0.19	0.151	1050
Al_2O_3 Powder	3.72	35	12.14	775
Tio_2 Powder	3.97	11.8	3.01	683



(a)Al_2O_3 Sample **Average Diameter 78.52nm**



(b)TiO_2 Sample **Average Diameter 52.56nm**

Figure 1: Atomic Force Microscopy Test for Al_2O_3 and TiO_2 Nano Powders

Thermal properties (thermal conductivity, thermal diffusivity, and specific heat capacity) for the composite material samples shown in figure (2) have been measured using hot disk test. Tested samples have been prepared according to (ISO-22007 standard) [20], with the dimensions of 30 mm diameterand 4 mm thickness.

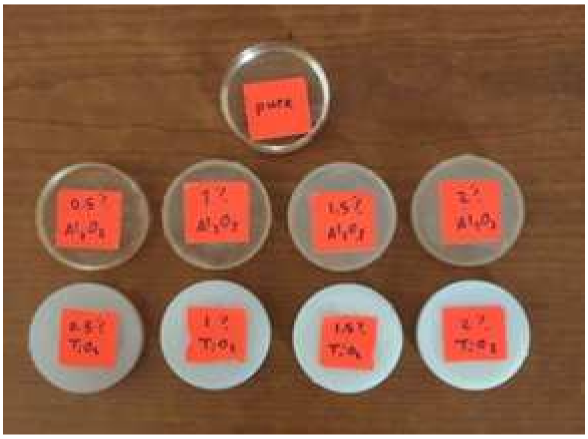


Figure 2: Samples of the Composite Specimens

RESULTS AND DISCUSSIONS

In order to verify the effect of adding Al_2O_3 and TiO_2Nanoparticles to the epoxy with different weight fractions on its thermal conductivity the obtained results were presented against the nanoparticles weight fraction as shown in figure (3). This figure shows that the thermal conductivity of the epoxy reinforced by Al_2O_3 and TiO_2 nanoparticles increases with the increasing the weight fraction of the fillers. It is also clear from this figure that the rate of increase in thermal conductivity for the specimens reinforced by (Al_2O_3)Nano powder is higher than those reinforced by (TiO_2)Nano powder. This can be attributed to the more conductive network due to the implementation of more Nano powder within the polymer matrix which forms acontinuous heat conduction part leading to transfer the heat more effectively. This finding was supported by that obtained in [21, 22]. This figure also shows that the maximum valueof thermal conductivity for the epoxy reinforced with 2% weight fraction(Al_2O_3) and (TiO_2)Nano powdersreach values of (0.55 W/m.K) and (0.492 W/m.K) respectively in comparison with the thermal conductivity of pure epoxy which was found to be (0.217 W/m.K).

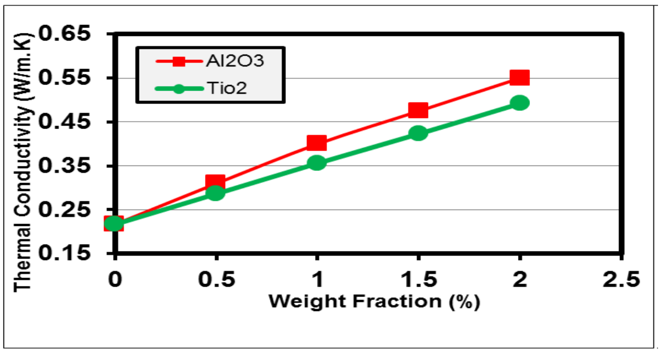


Figure 3: Thermal Conductivity against Weight Fraction of Al_2O_3 and TiO_2Nano Powders

The results obtained in this study also show that reinforcing the epoxy with different weight fractions of Al_2O_3 and TiO_2Nanopowders decrease the specific heat magnitudes of the composite materials as can be shown from figure (4). It is clear from this figure that the pure epoxy has a specific heat of (1.4515 MJ/m^3.K) which was higher than that of the Nanocomposites reinforced with different weight fractions of the Nanopowders. The lowest values of specific heat were found forcomposite material reinforced with2% weight fraction of TiO_2 and Al_2O_3Nano powders with values (1.2 MJ/m^3.K)and (1.222MJ/m^3) respectively. The decrease in heat capacity of the Nanocomposite materials can be attributed to the low heat capacity of used fillers.

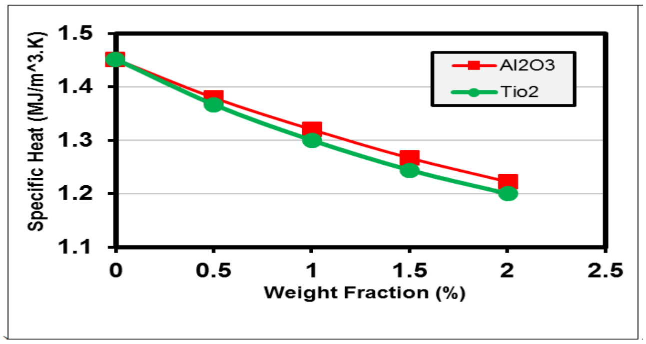


Figure 4: Specific Heat against Weight Fraction of Al_2O_3 and TiO_2 Nano Powder

Figure (5) shows the thermal diffusivity of epoxy reinforced with different weight fractions of (Al_2O_3) and (Tio_2)Nano powders. It is obvious from this figure that the thermal diffusivity of the Nano composite materialsincreases with the increasing of the weight fraction of (Al_2O_3) and (Tio_2) Nano powders. This can be explained by knowing that thermal diffusivity is directly proportional to the thermal conductivity and inversely proportional to the specific heatof reinforcing materials as indicated in equation(1). These results supported by that obtained in [19, 23]. Also this figure indicates that the thermal diffusivity of the pure epoxy is (0.1495mm^2/sec). The maximum value of thermal diffusivity for the epoxy reinforced with 2% weight fraction of (Al_2O_3) Nano powder equals to (0.45 mm^2/Sec.) while it becomes near (0.41mm^2/Sec) for that reinforced by TiO_2Nanopowder of the same weight fraction.

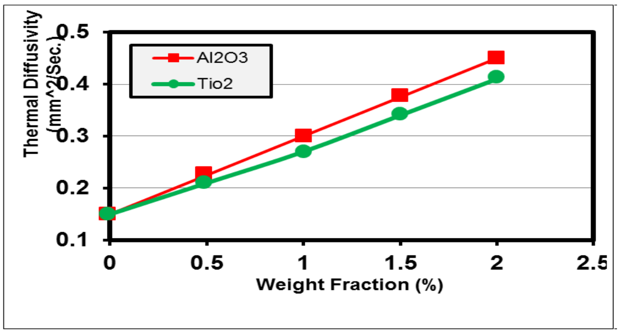


Figure 5: Thermal Diffusivity againstWeight Fraction of Al_2O_3 and TiO_2Nano Powder

CONCLUSIONS

- The pure epoxy has the lowest value of thermal conductivity and thermal diffusivity which reach (0.217 W/m.K) and (0.1495 mm^2/Sec.) respectively.
- The thermal conductivity and thermal diffusivity for the epoxy reinforced by Al_2O_3 and TiO_2Nanopowder increased with increasing the weight fractions of such Nanopowder.
- The maximum value of thermal conductivity and thermal Diffusivity equal to (0.55 W/m.K) and (0.45 mm^2/Sec.) when the epoxy reinforced by 2% weight fraction of reinforcing (Al_2O_3)Nano powder.
- Specific heat of the Nanocomposites decreases with increasing the weight fraction of reinforcing materials.

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